Shear Capacity of Half-cap Scarf Splices of Timber Bridges

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Abstract

Scarf joints were introduced to increase the length of half-caps for large width timber bridges. The current existing methodology to predict the shear capacity of scarf joints could be improved, as many of the evaluated scarf joints have been rated under capacity, using the modified notched beam equation from AS1720.1. This project aims to develop a more precise method to assess the shear capacity of the scarf joints, through an experimental test program. The project also aims to provide a better insight to the repair and maintenance of the existing half-cap scarf splices in timber bridges across Western Australia. As part of the test program, rectangular sections of timber beams with scarf joints will be tested under single point loading, with fixed-fixed end conditions. The variables that will be considered in the test program are the beam depth, distance of loading point from the fixed ends, sizes of bolts, configuration of scarf joints, scarf locations, and scarf slopes. Selected material properties of the timber samples, namely modulus of elasticity, bending strength, shear strength, compressive strength, and bearing strength have been obtained in accordance with AS 4063.1. Density and moisture content of the timber have been determined as per AS 1080.1. From the initial trial testing, it was observed that the experimental shear capacity of the scarf joints was higher than the theoretical capacities as per different design standards.

1. Introduction

A significant number of half-cap scarf splices exist in timber bridges in Western Australia. Most scarf joints have been found to be theoretically under-capacity even under dead loads, based on the existing guildlines (Australian standard AS1720.1,1988). Although cracking has been observed in some of the scarf joints, the cracks have generally been limited to less than 100mm and have not lead to the complete loss of structural capacity. The conceptual under-capacity referred to above demonstrates the extreme conservatism of the current methodology. As a result, many scarf splices, even those without any sign of distress, have been strengthened using steel parallel flange channel sections installed as supports underneath the half-cap segment containing the scarf joint. The lack of a realistic method to determine the strength capacity of scarf joints neccessitated a more representative method to assess the strength of the joints. The development of such a methodology would enable the asset owner to be assured about the safety of the bridge while avoiding unnecesarily repairing or replacing undamaged half-cap scarf joints.

The main objectives of the research project are to experimentally investigate the shear capacity of half-cap scarf splices considering several pertinent variables and to propose a load transfer and failure mechanism to assess the load capacity of scarf splices in shear.

1.1 Literature Review

Early work investigating scarf-splices through axial tension tests and bending tests have been conducted to analyse the structural behaviour of scarf joints. Types of scarf joints that have been investigated include half and tabled scarf joint, half and tabled tenoned scarf joint, nibbed scarf joint, fingered scarf joint, and splayed joint. To identify the structural behaviour of these joints, the stress concentrations generated at the joint have been investigated. Savin (1961) and Steida (1966) have reported that the stress concentration at the notch might influence the failure strength. The stress direction with respect to the grain direction, and any tension perpendicular to the grain have been reported to be the dominant factor that cause splitting and subsequent failure of timber scarf splices. Sangree and Schafer (2009) found that the failure strength of the joint is influenced by the slope of the grain, as it was found that sloped grain will be more prone to splitting. In addition, the stiffness of the tested halved and tabled scarf joint was observed to reduce by approximately 50%, even for the (small) grain slopes equal to 7 degrees. (Sangree & Schafer, 2009). The suggested conservative measure to cope with this sensitivity to grain inclination was to apply a factor of 0.33 to the shear strength parallel to the grain (Sangree & Schafer, 2009).

Karolak et al. (2020) found that the moment transfer of a scarf joint was about 30% of the solid beam. Their findings (Karolak et al., 2020) are supported by those of Larsen & Jensen (2000), where it was additionally found that a joint with dowel-type fasteners behaves semi-rigidly. However, scarf joints are generally designed as zero moment hinges to simplify the analysis (Larsen & Jensen, 2000), and in any case the bending moment contributes insignificantly to the failure. Chandler and Adsett (1998) reported that flexure and tension perpendicular to the grain direction are dominant failure modes in solid half-caps, even for beams with low span-to depth ratio where shear effects are higher. Aira et al. (2015) found that the strength and stiffness of the scarf is highly dependent on its geometry, by testing such scarf joints under axial tension and four-point bending, respectively. Even though, many different layouts of scarf joints have been investigated, for the particular half-cap scarf layout of interest to this thesis, no experiments have been done to date. As such, the suitability of the current capacity evaluation methodology that has been adopted for scarf layouts of existing timber bridges, which is derived from the bending of simple or tapered notched beams, has not been formally verified through experimentation.

2. Process

2.1 Test sample preparation

The geometry of the scarf joint was a scaled-down version of the typical full-scale half-cap scarf joint, with slight modifications made for practicality and testing constraints. To construct the model-scale scarf joint, manual cutting, computer numerical control (CNC) router, and water jet cutting were considered, and eventually the water jet cutting method was chosen to speed up the cutting process. Upon completion of the cutting process, the timber was sent to the UWA workshop to be drilled and fastened with bolts, in preparation for testing. To create effective fixity for the end conditions of the test setup, clamping steel plates were designed.

The pine timber that was sourced for the experimental testing had not been tested for any strength properties and there was also a general lack of such information from the timber suppliers. Hence, to better understand the material properties of the treated pine sleepers, some material characterisation tests have been conducted prior to carrying out the main test program. These tests include the determination of timber density, moisture content, compressive and bearing strength, modulus of elasticity, bending strength, and shear strength as per AS 4063.1 (2010) and AS 1080.1 (2012). Thereafter, the pine timber was accordingly characterised to the corresponding stress grades as per AS 2858 (2008) and AS 1720.1 (2010). The shear strength of the timber obtained in this manner is shown in Table 1, for reference. It should be noted that the shear strength noted in Table 1 is only a conservative prediction of the actual shear strength since the failure mode of all shear tests occured due to bending failure (which is mentioned as probable in the guidelines).

Test No.	Ultimate load (kN)	Shear stength (MPa)
1	44.3	2.06
2	46.2	2.16
3	51.4	2.42
4	50.9	2.39

Table 1 Shear strength parallel to grain of pine sleepers.

2.2 Methodology

For the planned experimental tests, the loading will be applied through an AMSLER testing machine, as shown in Figure 1, with two load cells attached to the fixed end enabling the actual load-effects to be determined. The level of fixities of the end supports will also be verified using an inclinometer and through manual calculations. For the fixed-fixed setup, six steel plates in total are required to achieve the fixities for both ends. Reactions at both ends would have to be determined which is planned to be achieved through two load-cells. The experimental results (shear capacity) will be compared with the capacities predicted as per current guidelines in use and will also thereafter be utilised to develop an improved method of assessment. To better represent the full-scale Jarrah half-cap scarf splice through the Pine model-scale specimen, it was attempted to closely match, as much as possible, the respective ratios between the timber shear force capacity to the bolt tensile force capacity, as shown in Table 2. A trial test was set up and completed to determine the shear capacity and the typical failure mode of the joint. The load was applied at a location so as to create zero moment close to the centre of the scarf joint. The orientation of the scarf joint was arranged so that the bolts would operate in tension.

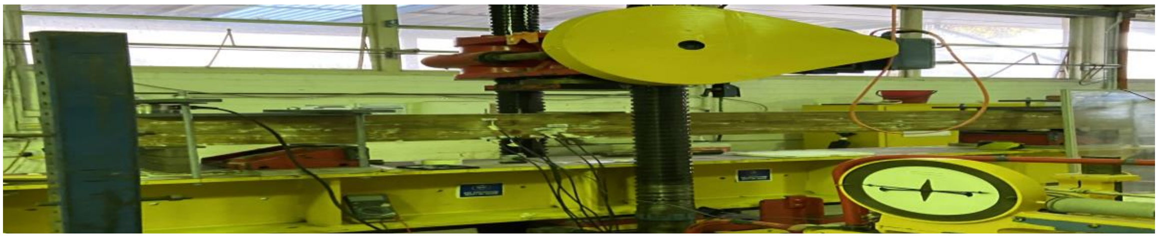

Figure 1 Trial test setup of the scarf joint.

Timber	Shear capacity (kN)	Bolt tensile capacity (kN)	Ratio
Jarrah (full scale)	265	98.0	2.70
Pine	36.1*	16.7	2.16

Table 2 Ratio comparison of the actual half cap scarf splice with the lab test.

* Based on the average strength value obtained from material characterisation tests.

* The cross-sectional area is 200 mm x 80 mm.

3. Preliminary Results and Discussion

The trial test results are shown in Figure 2 and Figure 3 below. The failure load was 31.9 kN, as shown in the load-time graph. This load was compared to the theoretical failure load, and it was found that this failure load was much higher than the predicted load, confirming the conservatism of the standards. The standards that were considered (Australian Standard 1720.1, Eurocode 5 EN1995-1-1 and CSA-O86) used the modified notched beam design equation, derived from a simply supported notched beam, to design the scarf joint. However, as proposed, the trial test used fixed end supports. The effectiveness of the strain gauge rosette used in the trial test was also ambiguous due to the grain structure of the timber. Thus, digital image correlation (DIC) method is planned to be trialled for the future tests.

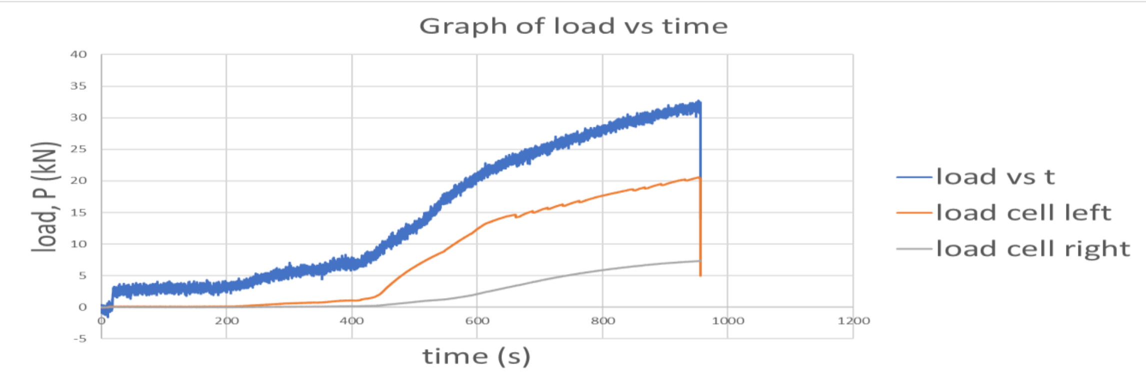

Figure 2 Load-time graph of the trial test.

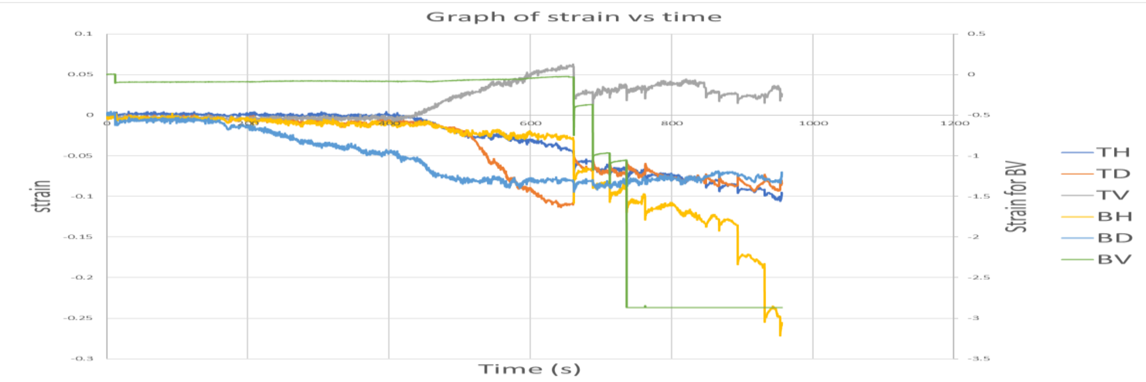

Figure 3 Strain-time graph of the trial test.

The fixities of the supports were verified by comparing the experimental and theoretical end moments, as shown in Table 3. It was judged that sufficient fixities had been achieved for both end supports.

End support	Theoretical (kNm)	Experimental (kNm)	Fixity achieved (%)
Left	-9.35	-7.64	81.7
Right	-3.55	-4.01	88.7

Table 3 Percentage fixity achieved for the trial test.

The load transferred to the joint had caused the bending of the of the washers, as shown in Figure 4. The washers compressed and indented into the timber at the vicinity of the bolt holes. Wood cracking sounds were heard during the test, which possibly corresponded to this indenting. However, eventually, the scarf joint failed through the shearing off of a nut from the

threaded rod, unexpectedly. Upon reviewing the component strength grades, it was found the nuts were made of Grade 4.6 steel, while the threaded rods were made of Grade 8.8 steel. Insufficient grip and insufficient strength of the nuts had caused this unexpected failure mode to occur, which will be rectified for the main test program (i.e. by using Grade 8.8. nuts).
By comparing the ratio of the bolt tensile capacity with the timber crushing capacity under the washers between full and model scales, as shown in Table 4, it was found that this sample joint did not exactly represent the actual splice. Since the timber used in the test was pine, the compressive capacity of the wood was much lower than Jarrah. Hence, for future tests, modifications will be made to the test design, by increasing the diameter and thickness of the washers, in order to improve the representativeness of the model-scale tests.

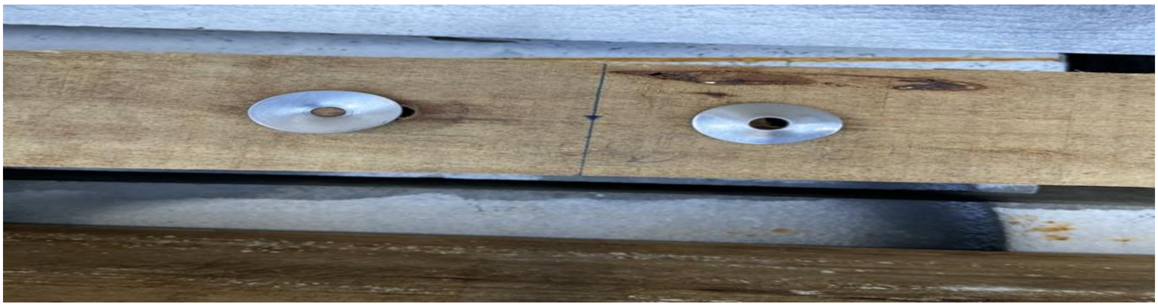

Figure 4 Bending of wahsers and indentation of the timber.

Timber	Bolt tensile capacity (kN)	Timber crushing strength (kN)	Ratio
Jarrah (full scale)	157	52.9	2.96
Pine	26.7	3.47	7.70

Table 4 Comparison between experimental test and actual half-cap scarf splices.

4. Conclusions and Future Work

The trial test failure load was significantly higher than the capacities predicted by different design codes. Failure at the vicinity of the scarf joints was observed, where the scarf joint was located at the theoretical zero moment location.

Future works for this project include completing the second trial and main experimental test program, the repetition of some material characterisation tests in relation to the main test samples and to analyse the results from the test program. Along with the comparison of experimental results to the predictions as per the current standards, sensitivity analysis will also be carried out. The DIC method, as shown in Figure 5, is hoped to be incorporated to the test setup and the results will be compared to the data collected from traditional strain gauges. In addition, a testing program of similar process and methodology is also planned to be performed for Jarrah test samples, utilising bridge deck planks supplied by Main Roads Western Australia. Manual theoretical calculation methods are hoped to be developed and compared to the experimental results, also considering the different failure modes of the scarf joints that may be observed from the test program.

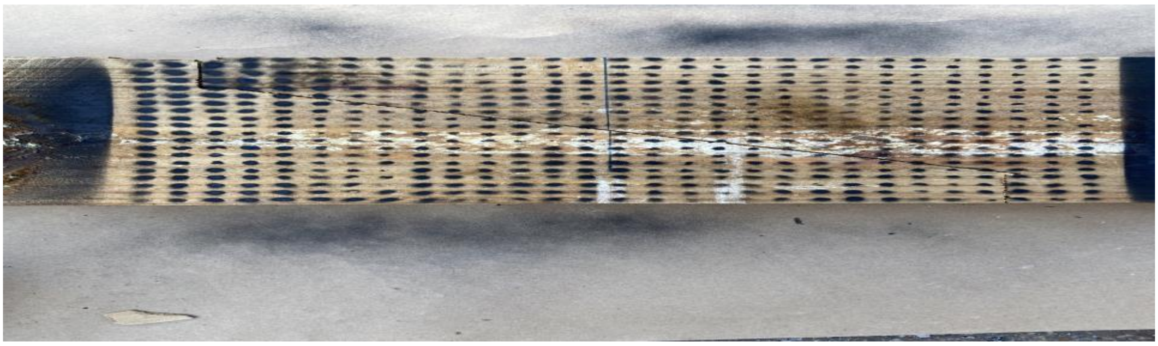

Figure 5 Speckles pattern with constant spacing to be used for DIC.

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